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**REGULATORY EVALUATION  
REGULATORY FLEXIBILITY ANALYSIS**

**Aluminum Cylinders Manufactured of Aluminum Alloy  
6351-T6 Used in SCUBA, SCBA, and Oxygen Service -  
Revised Requalification and Use Criteria**

**Docket RSPA-03-14405 (HM-220F)**

**January 2003**

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## **REGULATORY EVALUATION REGULATORY FLEXIBILITY ANALYSIS**

### **Aluminum Cylinders Manufactured of Aluminum Alloy 6351-T6 Used in SCUBA, SCBA, and Oxygen Service - Revised Requalification and Use Criteria**

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#### **Statement of the Problem**

Cylinders made of aluminum alloy 6351-T6 are known to be susceptible to sustained load cracking (SLC) in the neck and shoulder area. Research and Special Programs Administration (RSPA, we) has been notified of twelve SLC-related ruptures of DOT 3AL cylinders made of aluminum alloy 6351-T6 since 1994. Five of the twelve ruptures resulted in serious injuries. A review of manufacturers' data revealed that there have been several thousand cylinders that leaked, and many additional cylinders have been found to have cracks in the cylinder's neck during the normal requalification process. Research, testing, and analysis have been performed to determine whether there is any correlation between SLC and the probability of a cylinder rupture. The manufacturers' research and analysis indicated that the cylinders would leak and not rupture when operated at marked service pressure. RSPA performed additional metallurgical analysis on several ruptured cylinders to verify the cause of failure and failure mode. (See the metallurgical analysis reports at DOT web site, [http://hazmat.dot.gov/3al\\_cyls\\_info.htm](http://hazmat.dot.gov/3al_cyls_info.htm).) Those metallurgical analysis revealed that SLC caused the cylinder ruptures, but the results are inconclusive as to why the cylinders abruptly ruptured instead of leaking. Manufacturers stopped using aluminum alloy 6351-T6 in mid-1990 and started using aluminum alloy 6061-T6. Cylinders manufactured from aluminum alloy 6061-T6 are not susceptible to SLC.

The majority of the SLC-related ruptures occurred in SCUBA, SCBA and oxygen services. Additionally, for these services, the probability of cracking increases due to the increased frequency with which cylinders in these services are filled. RSPA estimates that approximately four million cylinders manufactured from aluminum 6351-T6 are in use in the SCUBA, SCBA, and oxygen services. These cylinders are of greatest concern to RSPA because they are used in close proximity to people, and a cylinder rupture may result in injury or death. We recognize that cylinders used in beverage service are also filled on a frequent basis. However, beverage service cylinders typically are filled to lower pressures than cylinders used in SCUBA, SCBA, and oxygen services, thereby reducing the stress levels to which beverage service cylinders are subjected.

## **Background**

In 1981, we adopted specification DOT 3AL under Docket HM-176, Specification for Usage Requirements for 3AL Seamless, Aluminum Cylinder (46 FR 62452, December 24, 1981). This new specification for a seamless aluminum cylinder, made of explicitly prescribed alloys, was based in part on the petitions received from industry and an agency initiative to consolidate and eliminate the need for seven exemptions authorizing the manufacture of seamless aluminum cylinders.

DOT 3AL cylinders manufactured of the 6351 alloy and heat treated to the T-6 temper condition have shown a tendency to develop SLC. While the exact cause and mechanism of SLC is not yet fully understood, it is believed that the cracks primarily originate from the bottom of the neck of the cylinder, at or below the lowest thread position in the interior of the cylinder. The cracking was first brought to RSPA's attention by persons retesting cylinders under the periodic retest procedures of 49 CFR 180.209.

We sent five cylinders suspected of having SLC to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, for analysis. The five cylinders had marked service pressures ranging from 1800 through 2200 pounds per square inch gauge (psig) and were made of both high lead content (100 parts per million or more) and low lead content (less than 100 parts per million) varieties of aluminum alloy 6351. The NIST inspection and examination confirmed that each of the five cylinders exhibited crack-like indications which were at least 0.050 inch deep.

Following the NIST analysis, RSPA requested that cylinder manufacturer Luxfer USA (Luxfer) provide available information concerning leaks or cracks in DOT 3AL cylinders. Luxfer provided information on the number of cylinders returned because of cracks or leakage.

The information revealed the following:

- (1) Of 3,278 cylinders made of high lead aluminum alloy 6351 with tapered threads, at least 33 (1.0%) are known to have leaked or had neck or shoulder flaws (e.g., cracks).
- (2) Of 60,000 cylinders made of low lead aluminum alloy with tapered threads, 23 (0.038%) are known to have leaked or had neck or shoulder flaws.
- (3) Of 312,000 cylinders made of high lead aluminum alloy 6351 with straight threads, 268 (0.086%) are known to have leaked or had neck or shoulder flaws.
- (4) Of approximately 5.02 million cylinders made of low lead aluminum alloy 6351 with

straight threads, 106 (0.002%) are known to have leaked or had neck or shoulder flaws.

RSPA believes that the above statistics do not fully represent the extent of the cracking and leakage problems, since NIST noted in its report that identification of cracking is very difficult even when an individual is specifically looking for cracks.

Work performed by Luxfer on neck cracking of DOT exemption hoop wrapped composite cylinders made of aluminum alloy 6351-T6 (which have neck and shoulder areas identical to DOT 3AL cylinders but operate at a higher operating stress level) indicated that cracking is a time dependent phenomenon that is accelerated when the lead content of the alloy exceeds 100 ppm. Further, it was found that the probability of cracking increases with an increase in stress level. Analysis of the stress levels present in the necks of DOT 3AL cylinders indicated that higher stress levels are present in cylinders with tapered threads. This analysis, confirmed by the in-service data, shows that the probability of neck cracking is much higher in DOT 3AL cylinders with tapered threads. Based on Luxfer's analysis and testing, it is anticipated that the frequency of cracks and leakage will increase with the length of time these cylinders are in service. Analysis shows that, for typical DOT 3AL cylinders made of aluminum alloy 6351-T6 (service pressure less than or equal to 3,000 psig), the failure mode is by leakage of the cylinder contents and not by bursting. It should be noted that, based on the information available to RSPA, cylinders made of aluminum alloy 6061, the other alloy authorized by specification DOT 3AL, are not susceptible to the cracking problems that have arisen in cylinders made of aluminum alloy 6351-T6.

It is our understanding that the overwhelming majority of DOT 3AL cylinders produced have been made of aluminum alloy 6351-T6. However, identification of the alloy used is not required to be stamped on the cylinder. The only way to determine which alloy was used to manufacture a cylinder is from the serial number applied by the manufacturer when the cylinder was made.

The aluminum alloy 6351-T6 has long been recognized as a potential safety problem. On July 10, 1987, we published a safety advisory and advance notice of proposed rulemaking (Docket No. HM-176-A; 52 FR 26027) to inform all persons possessing cylinders manufactured by Luxfer of aluminum alloy 6351-T6 that cracks had developed in some of these cylinders resulting in leakage and loss of cylinder contents. In addition to the safety advisory, the notice identified the cylinders at risk; suggested steps that users should take to minimize risks; and requested comment concerning the extent of the problem and possible corrective measures. We received 31 comments from manufacturers, distributors, and industrial users of aluminum alloy 6351-T6, including SLC behavior testing. The majority of the comments and findings concluded that cylinders made from aluminum alloy 6351-T6, including cylinders authorized under exemption DOT-E-7235, pose a greater probability of failure than other cylinders. Further, as stated earlier, it is difficult to detect cracks in these cylinders, a problem that adds to the safety risks. Unless determined otherwise, affected individuals should assume that a DOT 3AL or DOT-E 7235 cylinder manufactured outside the United States is constructed of aluminum alloy 6351-T6.

In January 1990, at our urging, cylinder manufacturers (e.g., Luxfer, Walter Kidde and Cliff Impact) voluntarily discontinued the use of aluminum alloy 6351-T6. There is sufficient data demonstrating that this alloy is not suitable for the manufacture of compressed gas cylinders and that it should be removed as an authorized construction material.

On August 8, 2002, we published a final rule (Docket HM-220D, 67 FR 51626 that amended the requirements of the HMR applicable to the maintenance, requalification, repair, and use of DOT specification cylinders. In that final rule, we added the following amendments pertaining to DOT specification cylinders made with aluminum alloy 6351-T6:

- We removed the authorization for the manufacture of DOT specification cylinders made with aluminum alloy 6351-T6.
- We prohibited these cylinders for Hazard Zone A materials effective on October 1, 2002. After that date, cylinders made of aluminum alloy 6351-T6 may not be filled and offered for transportation in toxic inhalation hazard service.
- We prohibited the use of cylinders made of aluminum alloy 6351-T6 for gases having pyrophoric properties.
- We required cylinders made of aluminum alloy 6351-T6 to be inspected for evidence of SLC in the neck and shoulder areas.

### **Current Cost of Injuries and Fatalities**

The Department of Transportation currently uses \$3,000,000 as the value of a statistical life. Injury values are a percentage of a fatality value, depending on the severity. Avoidance of a severe injury is estimated to have a value of \$562,500.

Estimation of the value of injuries or fatalities that would be avoided if SLC could be eliminated is complicated by the uncertainties due to the relative infrequency at which ruptures occur, and likelihood that aging cylinders may be progressively more prone to SLC.

RSPA is aware of 12 SLC related ruptures since 1994. They are occurring at the frequency of approximately 1.4 per year. We believe escalating that to a rate of 2.0 per year is appropriate because cylinders become more susceptible as they age.

Five out of twelve ruptures have resulted in serious injury, for a rate of 0.455 injuries per rupture. If the 2.0 rupture rate per year is accurate, one can expect 0.91 major injuries per year due to SLC.

Fortunately no fatalities have been reflected in incident history to date, but that trend is not likely

to continue over the long term and a certain proportion of ruptures can be expected to result in fatalities. Assuming one out of eight ruptures per year results in a fatality, one would expect 0.25 fatalities per year due to SLC.

The annual value annual of avoided injuries and fatalities, if the risk of SLC is eliminated, is shown in the following table.

Value of Avoided Injuries and Fatalities Per Year			
Type	DOT Value	Number Avoided	Value of Number Avoided
Severe Injury	\$562,500	0.91	\$511,000
Fatality	\$3,000,000	0.25	\$750,000
Total:			\$1,261,000

#### **Major Alternatives**

1. Do nothing (i.e., leaving the cylinders in service without taking any additional measures to reduce the risk.).
2. Removal of all of the cylinders manufactured of aluminum alloy 6351-T6 from service.
3. Perform a non-destructive examination (NDE) at the time of the cylinder's periodic requalification and recommend additional operational controls during the cylinder filling process.

#### **Alternative 1**

We could continue with current regulatory requirements. We estimate that the cost of this alternative to be \$1,261,000 per year. We do not believe this is the best alternative because it ignores a known safety problem. Additionally, if the cylinders used in these services (SCBA or SCUBA) fail while in use, it could pose a dangerous situation for the user.

#### **Alternative 2**

This option requires removal of all existing cylinders susceptible to SLC from service. At an average current value of \$ 100 each, we estimate the cost of removing 4,000,000 cylinders from service to be

\$400,000,000. This is not justifiable in terms of the value of avoided injuries and fatalities. In addition, such action has the potential to cause a serious shortage of breathing air cylinders used in firefighting and medical applications. The increased risk to human health and safety under such circumstances could offset much of the potential gains from eliminating the problem of SLC.

### **Alternative 3**

This option would require non-destructive examination (NDE) of cylinders at the time of the cylinder periodic requalification, which occurs every five years, and would recommend certain operational controls when filling the cylinder.

We estimate the cost of the hydrostatic test and internal visual inspection that is required under the current regulation to be \$5 per cylinder every five years. We estimate the NDE combined with the current hydrostatic and visual inspection to be \$7.25 per cylinder every five years. Therefore, we estimate the additional annual cost of the NDE to be \$0.45 per cylinder. The average annual cost of NDE is the annual cost per cylinder multiplied by the number of cylinders, or \$1,800,000. The cost of additional operational controls are nominal.

We estimate that NDE and the additional operational controls will reduce incidents, injuries and fatalities caused by cylinder ruptures by 90%. Benefits are thus \$ 1,261,000 x .90 or \$ 1,135,000.

### **Conclusion**

Of the three alternatives, RSPA believes that alternative 3 is the most prudent. It eliminates a known safety problem without incurring excessive cost. Although costs exceed benefits, there is enough uncertainty in the estimates to warrant action. Additionally, industry is already making significant increased use of NDE, and this action would align regulations with emerging industry practice.

## **Regulatory Flexibility Analysis**

The Regulatory Flexibility Act (5 U.S.C. 601 et seq.) requires an agency to review regulations to assess their impact on small entities unless the agency determines that a rule is not expected to have a significant impact on a substantial number of small entities. We have determined that, while the requirements in this rule apply to a substantial number of small entities, there will not be a significant economic impact on those small entities.

Need for the rule. Cylinders made of aluminum alloy 6351-T6 are known to be susceptible to sustained load cracking (SLC) in the neck and shoulder area. RSPA has been notified of twelve SLC-related ruptures of DOT 3AL cylinders made of aluminum alloy 6351-T6 since 1994. Five of the twelve ruptures resulted in serious injuries. Our review of manufacturers' data revealed that there have been several thousand cylinders that leaked, and many additional cylinders have been found to have cracks in the cylinder's neck during the normal requalification process. Research, testing, and analysis have been performed to determine whether there is any correlation between SLC and the probability of a cylinder rupture. The manufacturers' research and analysis indicated that the cylinders would leak and not rupture when operated at marked service pressure. RSPA performed additional metallurgical analysis on several ruptured cylinders to verify the cause of failure and failure mode. (See the metallurgical analysis reports at DOT web site, [http://hazmat.dot.gov/3al\\_cyls\\_info.htm](http://hazmat.dot.gov/3al_cyls_info.htm).) Those metallurgical analysis revealed that SLC caused the cylinder ruptures, but the results are inconclusive as to why the cylinders abruptly ruptured instead of leaking. Manufacturers stopped using aluminum alloy 6351-T6 in mid-1990 and started using aluminum alloy 6061-T6. Cylinders manufactured from aluminum alloy 6061-T6 are not susceptible to SLC.

The majority of the cylinders are being used in six major services: (1) SCUBA, (2) SCBA, (3) beverage, (4) medical oxygen, (5) industrial gases and (6) fire extinguishers. RSPA estimates that approximately four million cylinders manufactured from aluminum alloy 6351-T6 are in use in SCUBA, SCBA and oxygen services. These cylinders are of greatest concern to RSPA because they are used in close proximity to people, and a cylinder rupture may result in injury or death.

### Description of Proposed Actions

- We propose to require cylinders manufactured of aluminum alloy 6351-T6 used in SCUBA (diving), SCBA (firefighting), and oxygen service to undergo additional non-destructive examination at the time of the required five-year periodic requalification that would include an eddy current examination combined with a visual examination.
- We are also proposing that adequate safeguards be established to protect against potential injury and damage during the filling process.
- We are recommending that only individuals essential to the filling process be allowed in



the vicinity of the cylinder during the filling process.

Identification of potentially affected small entities. Businesses likely to be affected by the rule are cylinder manufacturers, cylinder requalifiers, independent inspection agencies, and commercial establishments that own and use DOT 3AL cylinders manufactured from aluminum alloy 6351-T6.

There are an estimated 188 manufacturers of high- and low-pressure cylinders. In addition, the Associate Administrator has approved about 2150 active domestic cylinder requalifiers and seven independent inspection agencies. There are also about 14 facilities approved to perform cylinder repairs and rebuilding. Cylinder requalifiers include businesses that manage large fleets of cylinders, such as cylinders charged with propane to power forklift trucks and for use by retail customers through cylinder exchange programs. Other companies manage fleets of cylinders used in carbon dioxide service for carbonated soft drinks, fire extinguisher service, and compressed air/oxygen breathing equipment used by emergency response personnel and in recreational diving. Finally, there are literally hundreds of commercial establishments that own and use DOT 3AL cylinders manufactured from aluminum alloy 6351-T6. These business sectors include agriculture; mining; construction; manufacturing; transportation; communications; electric, gas, and sanitary services; wholesale trade; retail trade; and other services. As stated earlier, the majority of the SLC related ruptures occurred in SCUBA, SCBA and oxygen services. Additionally, for these services, the probability of cracking increases due to the increased frequency in which cylinders in these services are filled. In SCUBA and SCBA services, the cylinder is attached to the back of a diver or firefighter, which substantially increases the risk of injury or fatality in the event of a rupture. Similarly, an oxygen cylinder may be placed close to a patient in the hospital or home. SLC could also result in an oxygen leak that may cause an explosion. Therefore, because of the higher risk in SCUBA, SCBA and oxygen services, HM-220F proposes to adopt a standard for early detection of SLC to reduce the risk of a cylinder rupture.

Unless alternative definitions have been established by the agency in consultation with the Small Business Administration (SBA), the definition of "small business" has the same meaning as under the Small Business Act. Since no such special definition has been established, we employ the thresholds published by SBA for industries subject to the HMR. Based on data for 1997 compiled by the U.S. Census Bureau, it appears that upwards of 97 percent of firms subject to this rule are small businesses. For the most part, these entities will incur minimal costs to comply with the provisions of the rule.

#### Reporting and recordkeeping requirements.

This NPRM includes one new requirement for reporting and recordkeeping. Specifically, in addition to the periodic requalification and marking described in § 180.209 for all DOT 3AL, cylinders manufactured of aluminum alloy 6351-T6 used in self-contained breathing apparatus, self-contained breathing apparatus, and oxygen service must be requalified and inspected for sustained load cracking using an eddy current examination combined with an external visual

examination as described in Appendix C to part 180. Other than the eddy current examination and visual inspection recordkeeping requirements there is no additional regulatory burden associated with the proposal.

The cost of hydrostatic test and internal visual inspection that is required under the current regulation is estimated to be \$5.00 per cylinder every five years. The additional NDE combined with the current hydrostatic and visual inspection is estimated to be \$7.25 per cylinder every five years. Since the NDE would take place at the time of the currently required five-year requalification period, the cost would be reduced substantially. Therefore, we estimate the annual cost of additional NDE to be \$0.45 per cylinder. Since most of the cylinders with critical size sustained load cracking would be identified and removed at the first NDE, the cost for the NDE would be reduced further over the second and third examinations. The average annual cost of NDE is the annual cost per cylinder multiplied by the number of cylinders or \$1,800,000. The cost of additional operational controls are nominal.